

VERSION OF AMENDMENTS WITH MARKINGS TO SHOW CHANGES MADE
(Dated November 30, 2001)

IN THE SPECIFICATION

Please amend the Specification, which consists of: (1) amended Pages 1 - 3, as filed September 4, 2001, before the IPEA/EP during Chapter II of the P.C.T. international phase; and, (2) of Pages 4 - 12, as being the literal English translation of the P.C.T. application filed on June 14, 2000:

Page 1, between lines 2-3 (immediately beneath the Title of the Invention), insert the following headings:

--BACKGROUND OF THE INVENTION--; and,
--Technical Field of the Invention--.

Page 1, lines 3-6, rewrite this paragraph to now read as follows:

--The invention relates to an electrostatic corrector for eliminating the chromatic aberration of particle lenses, with a straight optical axis [according to the generic part of Claim 1.] and an electrostatic quadrupole for allocating to an objective lens.--

Page 1, between lines 6-7, insert the following heading:

--Description of the Prior Art--

Page 2, between lines 23-24, insert the following heading:

--SUMMARY OF THE INVENTION--.

MARKED-UP AMENDMENTS-1

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Page 4, lines 1-7 (amendment to correct deletion of last three lines of literal English translation, which were erroneously deleted upon entry of Article 19 Amendments before the EP/IPEA on September 4, 2001), rewrite this paragraph to now read as follows:

--The proposed electrostatic corrector, in its preferred construction, comprises four elements arranged one behind the other in the direction of the straight optical axis, namely - in the direction of the optical axis starting from the objective - first of a quadrupole and two corrector pieces arranged one behind the other, and finally - at the output end - of a further quadrupole. The quadrupole fields of the two corrector pieces are rotated with respect to one another about an angle of 90° about the optical axis.--

Page 10, between lines 28-29, insert the following:

--BRIEF DESCRIPTION OF THE DRAWING FIGURE--

--The single drawing figure schematically illustrates the preferred construction and function of the electrostatic corrector of the present invention.--

--DETAILED DESCRIPTION OF THE DRAWING FIGURE

AND PREFERRED EMBODIMENTS --.

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Electrostatic Corrector for Eliminating the Chromatic
Aberration of Particle Lenses

The invention relates to an electrostatic corrector
for eliminating the chromatic aberration of particle
lenses, with a straight optical axis and an
electrostatic quadrupole for allocating to the
objective lens.

According to the Scherzer theorem (O. Scherzer,
Zeitschrift für Physik 101, (1936) 593), it is known
that in optical reproduction systems for charged
particles, which is understood to mean principally
electrons and ions, with the use of static, space-
charge-free and rotationally symmetrical fields, the
chromatic aberration (colour deviations) and
spherical aberration (focussing deviations) do not
necessarily disappear. Since these errors limit the
capability of the reproductive optical systems and in
particular the resolution capability, there has been
no lack of attempts to eliminate these image errors.
Most success is promised by the departure from
rotationally symmetrical lenses, that is to say the
use of non-circular lenses in the form of multipoles,
in particular quadrupoles, octopoles and the like. By
means of a corrector of this kind made up from
electrical and magnetic multipoles, the two managing
directors of the applicant have succeeded in
completely correcting the spherical and chromatic
aberration in a low-voltage scanning electron
microscope (J.Zach, M. Haider Nucl. Instr. method
A363 (1995) 316), wherein it was possible to

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demonstrate a resolution capability of 2 nm at an electron energy of 1 kV.

The disadvantages of the electromagnetic multipole correctors can be seen in the fact that, because of the remanence, the magnetic fields do not allow fast, precise and reproducible adjustment of the magnetic fields. A demagnetisation also requires removal of the coil cores, which represents considerable effort. Over a relatively long period, a relatively large drift of the magnetic fields occurs. Finally, the strong magnetic fields necessary in ion-optical devices, such as, for example, lithography, because of the large ion masses, can only be implemented with difficulty because of the dependency of focusing on the mass. Correctors for eliminating the chromatic aberration with purely electrical fields in both sections are not known.

On this basis, the object of the invention is to provide a corrector for eliminating the chromatic aberration of particle lenses, which is constructed entirely from electrical fields, that is to say without the use of magnetic fields.

This object is attained according to the invention in that two corrector pieces are arranged along the optical axis upstream of the quadrupole in the beam direction, each corrector piece has two electrical quadrupole fields with overlaid circular lens field, whose quadrupole fields, however, are rotated relative to one another through an angle of 90° about the optical axis, and the adjustment is carried out

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such that the astigmatic intermediate image of one section lies in one corrector piece and the astigmatic intermediate image, which is perpendicular thereto, of the other section lies in the other corrector piece, and finally a further electrostatic quadrupole is arranged at the output side.

The term chromatic aberration in the sense of the invention, in exact terminology, means the first order, first degree axial chromatic aberration.

10 Herein, the word "axial" describes the fact that this chromatic aberration is only determined by the fundamental paths emerging from the optical axis in the object point, that is to say the fundamental solutions to the Gaussian optics. The chromatic
15 aberration is thus independent of the extra-axial paths. The order describes the power to which the initial gradient of the fundamental path enters into the chromatic aberration; the first order case there is a linear dependency. The term "first degree"
20 describes the fact that the chromatic aberration has a linear dependency on the relative velocity deviation of the mean velocity of the particles. In the case of monochromatic particles - i.e. particles of equal velocity and therefore also constant
25 wavelength - the relative deviations thus become zero. In this case there is no chromatic aberration. In the language of optics, the chromatic aberration is often also termed "colour deviation".

30 The proposed electrostatic corrector, in its principle construction, consists of four elements arranged one behind the other in the direction of the

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straight optical axis, namely - in the direction of the optical axis starting from the objective - first of a quadrupole and two corrector pieces arranged one behind the other, and finally - at the output end -
5 of a further quadrupole. The quadrupole fields of the two corrector pieces are rotated with respect to one another about an angle of 90° about the optical axis.

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The beam path in the corrector travels as follows:
the axial beam path starting from the centre of the
10 object is first deflected by the objective lens and, after entry into the corrector, is first deflected by the electrical quadrupole in different manners in the two sections (X and Y section). The particle bundle is thereby focused in one section (e.g., in the X
15 section) and caused to diverge in the other section (Y section), so that an astigmatic intermediate image is produced, which passes through the optical axis and is expediently positioned in the centre of the first corrector piece. This corrector piece therefore
20 does not significantly affect the path trajectory in the section in which the intermediate image lies (X section), because the axial path passes close to the optical axis and intersects it, wherein positive chromatic aberrations do occur, but because of the
25 low distance from the axis they are only very small. In the section perpendicular thereto (Y section), on the other hand, the path trajectory, due to the quadrupole fields of the corrector piece, experiences a considerable influence and negative contribution to
30 the chromatic aberration. There is thus an influencing of the chromatic aberration of one

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section in the first corrector piece and, in an analogous manner, of that of the second section in the second corrector piece. In dependence on the set potentials, an influencing of the chromatic aberration and in the ideal case a compensation of the chromatic aberration of the objective lens follow, so that the entire optical system formed of the objective lens and corrector has reproduction properties free of chromatic aberrations. The last quadrupole serves to re-combine the ray path to rotational symmetry again.

The generation of the astigmatic intermediate image within the corrector piece, i.e. the zero crossing of the corresponding paraxial path can be achieved by appropriate choice of the strength of the electrical quadrupole present at the input of the corrector. Variation of the potential of the electrical quadrupole fields of the corrector piece (circular lens component as well as quadrupole field intensity) with respect to one another, that is to say the opposing field between the quadrupole fields, results in the influencing and setting of the chromatic aberration.

The decisive advantages of the electrostatic corrector consist in a rapid and precise adjustment and setting of the fields, a problem-free handling with reproducible conditions even over a relatively long time period and also in the possible use in ion-optical equipment.

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Particularly preferred embodiments are those in which a symmetrical construction and/or symmetrical course within a corrector piece with respect to its centre plane and/or a symmetrical construction and/or

- 5 symmetrical course of the fields of the two corrector pieces, with respect to the centre plane between them is provided. Because of the symmetrical/anti-symmetrical course of the paraxial paths within the corrector pieces, numerous error integrals are
- 10 cancelled out, or are at least made clear in an analytical manner and can be resolved without problem, which substantially contributes to the transparency and understanding of the behaviour of the corrector in different situations and settings.
- 15 The symmetry with respect to the centre plane of a corrector piece both in construction and in the setting of the electrical fields has the consequence that the zero crossing of the corresponding paraxial path comes to lie exactly in the centre plane. In
- 20 addition, the two outer quadrupole fields of the same corrector piece are then identical.

- Because of the construction and symmetry of the fields of the two corrector pieces, with maintenance of the relative rotation between them of 90° , an
- 25 identical path trajectory is obtained in both sections, i.e. the correction of one section made in the first corrector piece takes place in the other section in the second corrector piece.

- The resulting advantages are simple analytical
- 30 resolvability and, because of the clarity, a resulting understanding of the behaviour of the

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corrector. Not only the adjustment is simplified, but also the handling in general; the possibility of setting fewer potentials also contributes to simplification.

- 5 On the setting of the corrector:
In principle it is possible, by influencing the chromatic aberration, to achieve any optional setting of the chromatic aberration of the overall system consisting of an objective lens and corrector. Often
10 the declared aim is to make the overall aberration of the entire system zero, that is to say by means of the corrector to generate a negative chromatic aberration component, which compensates the further positive chromatic aberration generated from the
15 objective lens and the individual corrector elements. In the above-described symmetrical conditions, only two parameters are available for setting the corrector piece, namely the ratio of the outer and centre circular lens field and the intensity of the
20 quadrupole field.

The elimination of the chromatic aberration takes place in an iterative process, which in the case of the above-described symmetrical construction also becomes particularly clear, and is described below:

- 25 With a constant ratio of the two circular lens potentials of the corrector piece, the quadrupole intensity is varied, and thereby the chromatic aberration coefficient is measured. As soon as the chromatic aberration reaches its minimum value, the
30 ratio of the circular lens field is also varied with the aim of further minimising the chromatic

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aberration. By multiple interactive steps in the above-described manner, the chromatic aberration can then be completely eliminated. Mathematical considerations show that a complete correction of the chromatic aberration will only be possible for particular regions of the circular lens potentials of the corrector piece and of the quadrupole field intensities.

As mentioned at the outset, the capability of electron-optical imaging systems is limited by chromatic aberration and spherical aberration. The object of the above-described corrector consists in eliminating the first order, first degree axial chromatic aberration. In numerous applications, it is sought to additionally eliminate the spherical aberration, more specifically the third-order axial spherical aberration. To this end, octopole fields, that is to say fourfold fields, overlay the quadrupole fields. In the symmetrical construction described as a special embodiment, the octopole field overlays the centre quadrupole field of the corrector piece. Through the choice and setting of the intensity of the quadrupole field, a setting and, if appropriate, compensation of the third-order axial spherical aberration is completely decoupled from the setting of the quadrupole fields serving to eliminate the chromatic aberration.

For the constructional implementation, it is possible in a single multipole element to generate quadrupole as well as octopole fields.

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In a preferred further developmentf, it is proposed to arrange a further, third corrector piece in the direction of the optical axis upstream of the existing corrector consisting of two corrector pieces. Both as regards the spatial arrangement as well as the intensity of the quadrupole and circular lens fields, a mirror-symmetrical arrangement with respect to the centre plane of the second corrector piece and thereby with respect to the plane extending through the centre of the corrector consisting of three corrector pieces. As a result, a third corrector piece is obtained, which is of mirror-symmetrical construction to the first corrector piece. For the two axial elementary paths, that is to say elementary paths proceeding from the optical axis in the object point, the path proceeding in the alpha section has point symmetry with respect to centre of the corrector and the β -path proceeding perpendicular thereto has mirror symmetry with respect to the centre of the corrector. The extra-axial paths proceeding outside the optical axis are, as regards the gamma section, mirror-symmetrical with respect to the centre of the corrector, and the delta path extending in the plane perpendicular thereto proceeds point-symmetrically with respect to the centre of the corrector. In the first and third corrector piece, specifically in the astigmatic intermediate image of the β path, a correction of the chromatic aberration in the xz section takes place. In the middle (second) corrector piece, the correction in the yz section follows in the astigmatic intermediate image of the alpha path. In general, the chromatic aberrations are

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different in the two sections. The optimum setting of the corrector is then obtained when the excitation of the corrector pieces and the geometry, in particular the distance between the front quadrupole and first corrector piece and between the corrector pieces, is chosen such that optimum setting of the corrector is provided. By means of this change of the geometry, the incidence into the second corrector piece can be optimised. Although the path incidence into the first and third corrector pieces is then less favourable as regards the chromatic aberration correction in the xz section, this disadvantage can be eliminated by the fact that the correction in this section is distributed between two corrector pieces, and thereby a compensation becomes possible. Because of the symmetry of the paths and the fields with respect to the centre of the corrector, and thereby with respect to the centre of second corrector piece, all extra-axial with a linear axial distance can be eliminated. The possibility is obtained of transmitting an extended image field, with the consequence that this corrector is also suitable for use beyond the scanning electron microscope. A contribution to this is also the elimination of the image aberration of the coma. A further advantage of this arrangement is the reduction of the combination aberration and here in particular minimisation of the third and fifth order axial image aberrations.

Further details, feature and advantages of the invention can be taken from the following descriptive part, wherein the construction and function of the

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electrostatic corrector proposed according to the invention can be obtained with reference to the drawing. The paraxial paths α, β proceed from the object (1) and are deflected by the objective lens (2) which is subject to chromatic aberration. The corrector (3) consists in its basic construction of a quadrupole directed towards the objective lens (4), a first corrector piece (5) adjoining in the direction of the ray path (5) and a further corrector piece (6) arranged at a distance therefrom. As can be seen from the drawing, the quadrupole (4) effects a splitting in the axial paths α, β , which proceed in different sections, namely firstly in the direction of the optical axis (Z) and another section perpendicular thereto. The corrector piece (5) consists of three quadrupole fields (5a, 5b, 5c), which are symmetrical, i.e. the two outer quadrupole fields are equal in intensity and lie symmetrical to the centre quadrupole fields (5b). For production of a symmetrical ray path, a further quadrupole (7) is arranged at the output side.

The construction, symmetrical with respect to the centre plane (Z_M), of the corrector pieces (5, 6), which are only rotated relative to one another through 90° with respect to the optical axis (z), results in an equal path trajectory in the section plane rotated through 90° . One corrector piece (5) effects an influencing and elimination of the chromatic aberration in that sectional plane in which the α path proceeds. The other corrector piece (6) acts on the β path proceeding in the other section,

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so that each of the corrector pieces (5, 6) effects the influencing or even the elimination of the chromatic aberration in one of the two sections. All quadrupole and circular lens fields are of

5 electrostatic nature.

Not drawn is the fact that, by overlaying of octopole fields, principally in the region of the astigmatic intermediate images, a correction of the spherical aberration (3rd order axial focussing deviation) can

10 be carried out. A considerable influencing of the efficiency of the particles of optical imaging systems can be achieved by elimination of the chromatic aberration and possibly also of the spherical aberration.

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